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Review Article

Recent Progress and Applications of Industries 4.0 in Nano Era In: A Review

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Abstract

The manufacturing industry is one of the sectors that are influenced by the fourth industrial revolution. Similarly, manufacturing is moved from Industry 3.0 phase into the industry 4.0 phase. In industry 4.0 the manufacturing machines are connected to a virtual environment for each physical machine that presents the manufacturing process in real-time. Therefore, factories are one of the entities that are encouraged to retrain and develop their operators to be able to gain all benefits of industry 4.0. The nanotechnology is a major breakthrough and is revolutionary as it will create extraordinary Nano world in the present century. This research paper aims to clarify the required knowledge and learning for a worker to operate the manufacturing processes associated with some of the capabilities of Industry 4.0 and Nano technology. This study provides several results, the most important of which is the focus on the rehabilitation of operators using modern technologies in alignment with the Fourth Industrial Revolution.

Keywords: Industry 4.0; Nanotechnology; IoT; Manufacturing; Machines

Introduction

The era we are living in these days is that of the digital revolution, which first took place the last quarter of the last century. This era is characterized by the fusion of all the techniques that have been developed, so that the physical, digital, and biological fields have overlapped, and the lines between them have blurred. Therefore, the need to move from the third revolution to a new one arised. There are three reasons why these transformations are unique and not merely an extension of the previous revolution. These reasons are the speed of change, its scope, and the impact of these transformations on the prevailing systems. The speed of the current scientific breakthroughs has no parallel in human history, since there is an amazing speed in the development of digital technologies, compared to that of the previous industrial revolutions [1]. Hence, the Fourth Industrial Revolution is the impact of technology, the Internet, and computers on various sectors of development and labor, including material science, robots, nanotechnology, three-dimensional (3D) printing, unmanned aerial vehicles, digital computing, and globalization [2,3]. The Fourth Industrial Revolution is based on the digital revolution, in which technology is an integral part of the society and a link between the digital, physical, and biological worlds. It is characterized by the use of advanced technology in various fields to improve efficiency and promote development and growth [4]. The new mechanisms in the industry focus on technical education and the development of young people skills. In different sectors of industry, which works to support the direction of political leadership in human development and devotes attention to human capital because this is the basis of any industrial revolution and development. Investing in the human workforce has become more important than ever before, as the world faces economic and social-environmental challenge [5]. The Fourth Industrial Revolution has added new pressures on the labor markets. Therefore, lifelong learning, learning reform, and new skill retraining initiatives will be the key to ensure that individuals have an effective economic opportunity to compete in the new world of work. Companies will also have the opportunity to attract the talented employees they need for future jobs. According to the World Economic Forum, at least 54% of all employees will need to be taught additional skills by 2022 [6]. Therefore, public and private sectors are required to hire new talented employees or train their employees to gain all the required knowledge to implement the latest technologies of Industry 4.0 Revolution. The manufacturing industry is one of the sectors that are influenced by the fourth industrial revolution. Similarly, manufacturing is moved from Industry 3.0 phase into the industry 4.0 phase. In industry 4.0 the manufacturing machines are connected to a virtual environment for each physical machine that presents the manufacturing process in real-time [7]. Therefore, factories are one of the entities that are encouraged to retrain and develop their operators to be able to gain all benefits of industry 4.0. The nanotechnology is a major breakthrough and is revolutionary as it will create extraordinary nano world in the present century [8]. The study of everything between 1-100 nm is known as nanotechnology. For example, DNA molecule- the blueprint of life and basis of the genome is twisted double strand of molecules with size of about 2nm. Surprisingly, the width of human hair is approximately 80000 nm. More appropriately, nanotechnology is the creation of functional materials, devices and systems through control of matter at the range of 1-100 nanometers. Using nanotechnology researchers and manufactures can fabricate materials literally molecule by molecule (*Mansoori* et al. 2005).

Nanotechnology is enhancing the quality of everyday products cosmetics, sunscreen, golf balls, clothing and cell phones by the use of nanoparticles and other Nano devices, and therefore it has become an important technology of 21st century. Richard Feynman in 29 December 1959 delivered a historical lecture at the annual meeting of American Physical Society at Caltech. Feynman gave his address entitled "There is a Plenty of Room at the Bottom". In 2002, Clinton announced the new national initiative popularly known as National Nanotechnology Initiative (NNI) to foster the tools of "next industrial revolution" [9]. The range of technologies that could significantly affect production and distribution is great. The technological possibilities of production are continuously expanding, with technologies complementing and amplifying each other's possibilities in combinatorial ways. Indeed, retrospective analysis shows that predictions of technological timelines-when certain milestones will be reached-tend to be particularly inaccurate (Armstrong, Sotala and ÓhĖigeartaigh, 2014). A small sampling, examined in recent work, includes.

- robots, which are set to become less costly, smaller, more intelligent, autonomous, and agile an increased connectedness of parts, components and machines to the Internet
- synthetic biology, which among other applications could allow petroleum-based products to be manufactured from sugar-based microbes, and bring the life sciences closer to engineering
- 3D printing which involves printing of complex materials
- Nanotechnology which allows new properties to be impacted to new materials.

Risks will arise with technological change in production. The various risks will have higher or lower probabilities, and more or less significance, for different countries and population groups. For instance:

- The effect of technological change on employment and earnings inequality is drawing increased attention from academics, policymakers and the public.
- Policymakers in some countries fear the consequences of unpreparedness in the face of rapid but hard-to foresee technological change. As this report shows, unpreparedness might take various forms-from skills and infrastructure deficits to regulatory shortcomings- and have numerous consequences.
- As a corollary to the risk of machine-driven labour displacement, automation might undermine labour cost advantages on which many emerging economies rely [10].
- As production systems become more complex and ICT-mediated, the risks and consequences of system fragility may increase [11]. while the ability to anticipate failures in technology could diminish [12].
- Risks also exist that potentially beneficial technological advances might be held back by a lack of public understanding or social acceptance.
- And innovations could create new hazards that need to be countered. For instance, some nanoparticles might have harmful effects on health. And ICTs allow ever more scientific information to be available to ever larger numbers of people, with some of this information-such as genetic information-being potentially dangerous. An important issue is the productivity effect of new production technologies. A main message is that much unexploited potential for productivity growth exists. A number of other cross-cutting policy considerations are also critical, ranging from issues of technology diffusion to IP concerns, to the practice of foresight. In addition, technology-specific policy lessons can be learned, including the following:
- Two trends mean that digital technologies are transformational for production: (i) their falling cost, which has allowed wider diffusion; and, most importantly, (ii) the combination of different ICTs, and their convergence with other technologies. Data-driven innovation (DDI) is transforming all sectors of the economy and digital technology is also making industry more services-like. Cloud computing and the IoT, among other technologies, will bring radical change. The pervasive nature of digital technology raises many policy challenges. For instance, coherent data governance frameworks are needed, barriers to ICT diffusion, interoperability and standards should be lowered, and complex and sometimes new issues of liability, competition, privacy and consumer protection need well-designed regulations and effective implementing institutions.
- The tools also exist today to begin a bio-based revolution in production. Governments can assist the supply of sustainable biomass for bio-based production and help resolve technical and economic questions about production, often through public-private partnerships. Governments can also lower barriers to trade in bio-

based products, lower regulatory hurdles that hinder investment, support the necessary interdisciplinary science and education, and develop markets using public procurement. Nanotechnology can enable many areas of production. Nanotechnology needs international collaboration, as many of the research and engineering tools are hard to gather in a single institute (or even region). Policymakers should develop multidisciplinary networks and support innovation and commercialization in small companies. Timely and clear guidelines are needed for assessing the risk of nanotechnology-enabled products, as is international harmonization in this area. Since 2006, the OECD has led international efforts to harmonies regulatory approaches to the safety of nanotechnology-enabled products.

- 3D printing includes a group of technologies and processes that use a digital file to build a physical three-dimensional object using additive manufacturing. Governments can: (i) target grants or investments to commercialize research in these directions; (ii) remove IP barriers to enable 3D printing of repair parts for legacy products (for instance, washing machines no longer in production). This research paper aims to clarify the required knowledge and learning for a worker to operate the manufacturing processes associated with some of the capabilities of Industry 4.0 and Nano technology. This research focuses on operators whose factory is moving from Industry 3.0 into Industry 4.0. Interviews were conducted with individuals who work for Industry 4.0, including vendors of technology, education vendors, employers, and operators who work in factories capable of adopting Industry 4.0 technologies. This study provides several results, the most important of which is the focus on the rehabilitation of operators using modern technologies in alignment with the Fourth Industrial Revolution. Two trends make digital technologies transformational for production: (i) their falling cost, which has allowed wider diffusion; and, most importantly, (ii) the combination of different ICTs, and their convergence with other technologies (thanks in particular to embedded software and the IoT). In a highly stylized way, (Figure 1) depicts the key ICTs which are enabling the digital transformation of industrial processes. The technologies at the bottom of Figure 1 enable those on top, as indicated by the arrows. The technologies at the top of Figure 1-including additive manufacturing (3D printing), autonomous machines and systems, and human-machine integration-are the applications through which the main productivity effects in industry are likely to unfold. The use of the above technologies in industry has been described variously as "Industry 4.0", the "industrial Internet" and "network manufacturing" The term "big data" refers to data characterized by their volume, velocity (the speed at which they are generated, accessed, processed and analyzed) and variety (such as unstructured and structured data). Big data promises to significantly improve products, processes, organizational methods and markets, a phenomenon referred to as DDI. Firm-level studies suggest that using DDI can raise labour productivity by approximately 5% to 10%, relative to non-users [13]. DDI will impact on production and productivity in services, manufacturing and agriculture. In the 1980s, Rolls Royce began selling "power by the hour", a development made possible by ICTs. Today the IoT allows manufacturing companies to monitor the actual use of their goods and thus provide customized pay-as-you-go services. These services are priced based on real-time operating data. Manufacturers of energy production equipment, for instance, increasingly use sensor data to help customers optimize complex project planning. Cloud computing allows computing resources to be accessed in a flexible on-demand way with low management effort. Many high-potential industrial applications of ICTs, such as autonomous machines and systems, and complex simulation, are very computationally intensive and require supercomputers. Especially for start-ups and SMEs, cloud computing has increased the availability, capacity and affordability of computing resources. But significant variation exists across countries and firms in the adoption of cloud computing (Figure 2). There is also large variation in use by size of business, with larger enterprises more likely to use cloud computing. As a percentage of enterprises in each employment size class Notes: Data for Belgium, Denmark, Finland, Greece, Hungary, Ireland, Latvia, Lithuania, Norway, Poland, Slovak Republic, Slovenia, and Spain refer to 2014. Data for Canada and Mexico refer to 2012. Data for Canada only include the use of SaaS, a subcategory of cloud computing services. Source: Based on OECD (2017b), OECD. Stat, database, http://dotstat.oecd.org/index.aspx?DatasetCode=ICT_BUS (accessed March 2017). The term "IoT" refers to the connection of devices and objects to the Internet's network of networks. Thanks to new sensors and actuators, and in combination with big data analysis and cloud computing, the IoT enables autonomous machines and intelligent systems. The IoT can bring improved process efficiencies, customer service, speed of decision making, consistency of delivery and transparency/predictability of costs [14]. The IoT will also bring major economic and social benefits not directly related to production, for instance in health and in vehicle efficiency. Companies increasingly divide their digital processes-hosting, storage and processing-across many countries. Countries are highly interdependent in terms of data flows. Countries which are home to major providers of digital services are likely to also be major destinations for cross-border data flows (from which those digital services are constructed). Conversely, countries which host major users of ICT-related services are often major sources of the data underpinning those services. The digitalization of production requires the diffusion and use of key ICTs. However, many businesses, and in particular SMEs, lag in adopting ICTs. For instance, the adoption of supply chain management, enterprise resource planning, and radio frequency identification (RFID) applications by firms is still much below that of broadband networks or websites. But it is these advanced ICTs that enable digitalized industrial production. An important aspect of interoperability for the IoT is identification and numbering policies. An issue that warrants special attention by governments and regulators is the liberalization of access to international mobile subscriber identity (IMSI) numbers. IMSI numbers allow different sectors of the economy, such as car manufacturers and energy companies, to have access to SIM cards without being obliged to go through mobile operators. This would provide these sectors with more flexibility when selecting a specific mobile network and ease the deployment of the IoT across borders. The Netherlands was the first country to liberalize access to IMSI numbers.

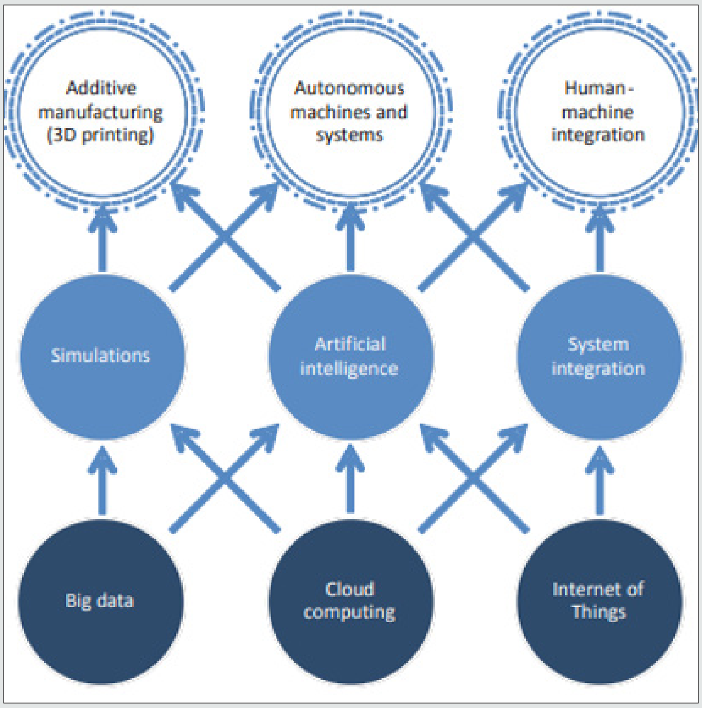

Figure 1: The confluence of key technologies enabling the industrial digital transformation (McKinsey Global Institute, 2013).

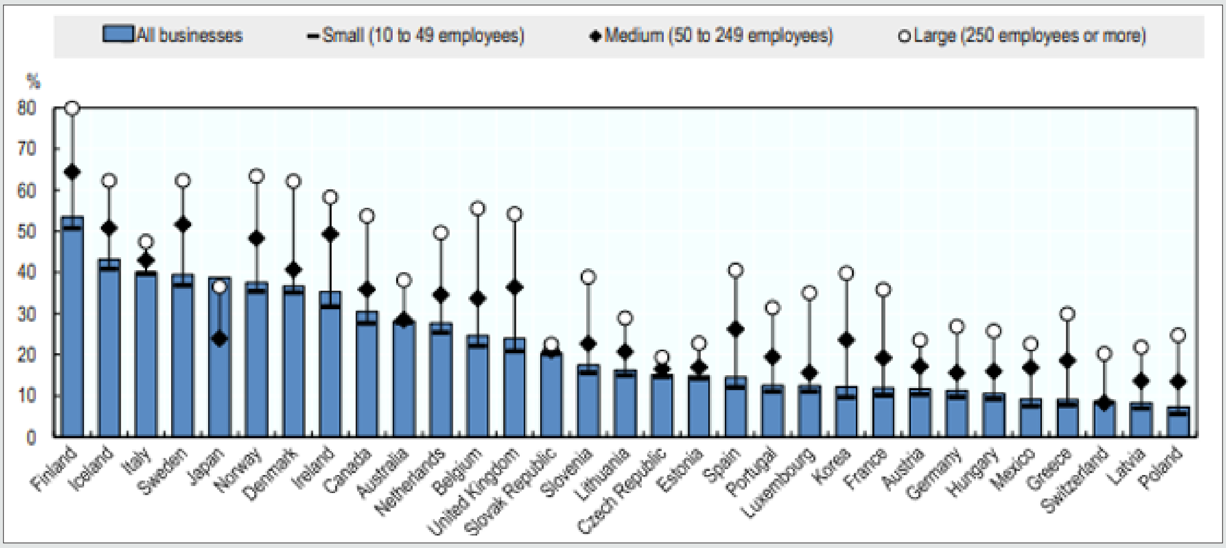

Figure 2: Enterprises using cloud computing services by employment size class, 2014.

Digital technologies also underpin the development of robotics

Robots first entered industry-initially in the automotive sector-in the 1960s. For decades, industrial robots were large, expensive, operated from static positions indoors, and performed one or a small number of repetitive and sometimes hazardous tasks, such as welding and machining. But a convergence of digital and other technologies has yielded a second generation of robots. These are smaller, less expensive, more autonomous, more flexible and cooperative. They can be programmed and used by average workers. Kuka, for instance, makes autonomous robots that collaborate and automatically adjust their actions to fit the next unfinished product [15,16]. Some robots even perform tasks by imitating workers. Robots also have new roles in services. The market for personal and household service robots is growing by about 20% per year, and prices are expected to decline quickly in the near future [17].

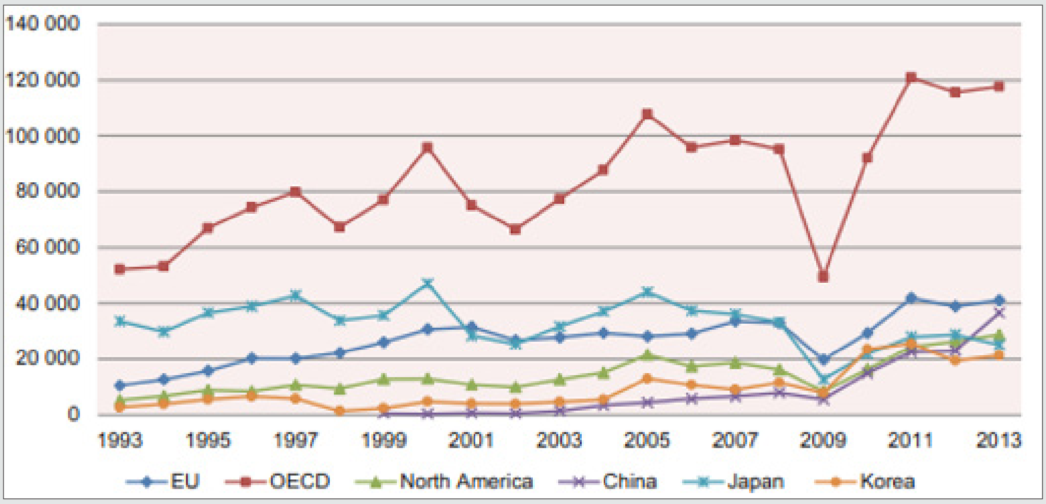

Figure 3: Global sales of industrial robots, 1993-2013 (McKinsey Global Institute, 2013).

Note: Data for China spans 1999-2013. Source: IFR Statistical Department at World Robotics, www.worldrobotics.org. Robot utilisation varies greatly across countries: 48% of Spanish firms and 44% of Danish firms used at least on industrial robot in 2009, compared to just 23% of firms in the Netherlands [18]. More intelligent and autonomous robots will come about through improvements currently being seen in computing performance, electromechanical design tools and numerically controlled manufacturing, electrical energy storage and electronics power efficiency, the availability and performance of local wireless digital communications, the scale and performance of the Internet, and global data storage and computational power [19]. Challenges remain, particularly in perception (recognizing specific objects in cluttered environments), manipulation and cognition. The next generation of miniaturized, complex products with short life cycles will require a level of assembly adaptability, precision and reliability which exceeds human capabilities [16]. And as populations age, robots will help to relieve demographic constraints on production. As well as increasing process reliability, robots reduce lead times for finished manufactured goods, allowing greater responsiveness to changes in retail demand. European manufacturers that use robots are more efficient than non-users. And such robot users are less likely to relocate production outside Europe [18]. Robot use increases strongly with firm size. This size-sensitivity reflects the greater financial resources, experience with advanced production technologies, and economies of scale available to larger firms.

Bio-production and industrial biotechnology

Petro-chemistry dramatically changed production in the early twentieth century. Several decades of research in biology have now yielded synthetic biology and gene-editing technologies. When allied to modern genomics-the information base of all modern life sciences-the tools are in place to begin a bio-based revolution. Everyday chemicals and fuels represent the largest market for bio-based products. In the last few years, the technology to produce entirely non-natural chemicals has been proven. This technology is now being commercialized Industrial biotechnology could improve the productivity and competitiveness of the chemicals sector by improving environmental performance. Biotechnology also offers unique solutions to dependence on oil and petrochemicals. For example, a hugely demanding task is to create food crops that make their own fertilizer, through synthetic biology and, in the near future, gene editing [20]. If achieved, this outcome would help to de-link agriculture from the fossil-fuel based fertilizer industry. Bio-based materials and fuels currently suffer in competition with the fossil-based industry. Over decades, oil and gas supply chains and production processes have been perfected. The production plants are mature and completely amortised, and the economies of scale achieved mean that fossil-based industries produce many products at low cost. Furthermore, fossil-fuel subsidies are vast. For bio-based products, none of these conditions exist. Investing in bio-based manufacturing-the most potent symbol of which is the integrated bio-refinery-has been a major risk: the early products have not been price competitive; markets have had to be created by government, and supply chains-particularly the collection of biomass-are far from perfected. However, nascent bio-based manufacturing is bringing new products to market. Indeed, almost one hundred bio-based chemicals are close to commercialization [21].

Nanotechnology: An enabler to the next production revolution

The term "nano" describes a unit prefix (1 nm = 1 x 10-9 m. A sheet of paper is about 100 000 nm thick). The widest definitions of nanotechnology include all phenomena and processes occurring at a length scale of 1 nm to 100 nm. The power and versatility of nanotechnology stem from the ability to control matter on a scale where the shape and size of assemblies of individual atoms determine the properties and functions of all materials and systems, including those of living organisms. The command of materials on the nanometer-scale can enable innovation in all existing industrial sectors. As it develops, nanotechnology will enter a widening range of uses and require complementary technologies and institutions. In the 1980s, science- and technology-foresight studies envisaged rapid advancements in nanotechnology. Progress in the science and its application, however, has been significantly slower than expected. Progress has been slowed by the high cost of R&D instrumentation, as well as by failures to scale-up from laboratory-scale procedures to industrial manufacture. The difficulty of achieving commercial-scale production was largely due to inadequate understanding of the relevant physical and chemical processes, and the inability to control production parameters at that scale. However, over the last ten years techniques for large-scale production of nanotechnology-based materials have improved significantly. Nanotechnology is increasingly used in production processes and manufactured products. For instance, nanotechnology can enable the replacement of energy-hungry production processes (such as the fabrication of solar cells in zone-melting processes) with low-cost processes (such as roll-to-roll printing of solar cells in ambient air) Nanotechnology requires increased efforts in institutional and possibly international collaboration. The entirety of research and engineering tools required to set up an all-encompassing R&D infrastructure for nanotechnology might be prohibitively expensive. State-of-the-art equipment costs several million euros and often requires the construction of bespoke buildings. Moreover, some of the most powerful research instruments exist as prototypes only.

It is therefore almost impossible to gather an all-encompassing nanotechnology infrastructure within a single institute or even region. Consequently, nanotechnology requires increased efforts in inter-institutional and/or international collaboration to advance to its full potential. Publicly funded R&D programmers should allow the involvement of academia and industry (both large and small companies) from other countries. The creation of networks that involve academia, public research laboratories and large and small companies (including those from other countries) creates an environment in which a research infrastructure can be shared, while simultaneously helping start-ups to establish themselves within a current or potential commercial value chain. Support is needed for innovation and commercialization in small companies. The relatively high cost of nanotechnology R&D hampers the involvement and success of small companies in nanotechnology innovation. Nanotechnology R&D is mainly conducted by larger companies. Policy makers could seek to improve SMEs' access to equipment by: (i) increasing the amount of money SMEs get in research grants; (ii) subsidizing/waving the service fee; or (iii) providing SMEs with vouchers for equipment use. Nanotechnology tends to thrive at the interface of traditional disciplines. This is where discipline-specific research and engineering infrastructures are available-favoring multidisciplinary-and the expert knowledge in traditional disciplines is pooled. Examples of such conducive environments include virtual networks, such as Germany has created to support biomedical nanotechnology, and research institutes such as the United Kingdom's Interdisciplinary Research Collaborations. As a general-purpose technology, nanotechnology has an impact on a wide range of industry sectors. Policy instruments may need to be designed in ways that take into account the multidisciplinary approaches that nanotechnology can require. Regulatory uncertainties severely hamper the commercialization of nano-technological innovation. This is because products awaiting market entry are sometimes shelved for years before a regulatory decision is made. In some cases, this has caused the closure of promising nanotechnology start-ups, while large companies have terminated R&D projects and innovative products. Policies should also support the development of transparent and timely guidelines for assessing the risk of nanotechnology-enabled products, while also striving for international harmonization in such guideline.

3D printing, production and the environment

3D printing is expanding rapidly owing to falling printer and materials prices, the rising quality of completed objects, and innovation. The global 3D printing market is projected to grow at around 20% per year from 2014 to 2020 [22]. Recent innovations permit 3D printing with novel materials-such as glass and metals-as well as printing of multi-material objects-such as batteries and drones. DNA printers and printing of body parts and organs from a person's own cells are under development. 3D printing could augment productivity in a number of ways. For instance, 3D printing of already-assembled mechanisms is possible, which could reduce the number of steps in some production processes. And design processes can be shortened, owing to rapid prototyping [23]. Objects can also be printed which are otherwise impossible to manufacture (such as metal components contained within other closed and seamless metal components). Currently, most 3D printing is used to produce prototypes, models and tools, with only 15% producing parts in sold goods [24]. In manufacturing, machining is the main method used for prototyping and producing limited amounts of custom parts. 3D printing is already significantly altering the market for machined plastic and metal parts. For instance, Boeing has already replaced machining with 3D printing for over 20 000 units of 300 distinct parts [25,26]. However, machining is a small industrial niche, comprising no more than a few percent of total manufacturing sales. Expansion of 3D printing into other industries depends on the technology's near-future evolution in print time, cost, quality, size and choice of materials. The main factor driving or limiting expansion of 3D printing is the cost of switching from mass-manufacturing methods to 3D printing. Costs are expected to decline rapidly in coming years as production volumes grow [17]. although it remains difficult to predict precisely how fast this technology will be deployed. Furthermore, the cost of switching is not linear. 3D printing will rapidly penetrate high-cost, low-volume industries such as prototyping, automotive tooling, aerospace and some medical devices. But 3D printing will more slowly penetrate moderate-cost, moderate-volume industries. The environmental effects of 3D printing on two important industrial technologies-machining and injection moulding- are particularly interesting to consider. These technologies represent two ends of a spectrum: single-unit prototyping and mass-manufacturing. Even considering these restricted cases, the environmental impacts of 3D printing vary widely. Printer type, frequency of printer utilization, part orientation, part geometry, energy use and the toxicity of printing materials all play a role. Some experimental systems already have far lower environmental impacts per part than injection moulding-perhaps 70% lower in some circumstances. Industry is not trending towards such systems, but policy could encourage socially desirable choices. Two of the most frequently claimed sustainability benefits of 3D printing-eliminating waste and transportation-fail to take into account the need for high purity materials that often cannot be recycled and the need for feedstock materials to be transported to the printing site. Many printing methods require such a high level of material purity that they discourage recycling. Nevertheless, 3D printing can enable more sustainable material use because: • It permits many materials to be shaped in ways previously possible only with plastics. • It lowers barriers to switching between materials by reducing economies of scale in some processes. • It can allow fewer chemical ingredients to yield more variation in material properties by varying printing processes. 3D-printed parts can also lower the environmental impacts of some products because of how the products can be used, even if environmental impacts during manufacturing are high. This can happen in two ways:

(i) by printing replacement parts for legacy products that would otherwise be discarded; and

(ii) by reducing a product's weight or otherwise improving a product's energy efficiency (General Electric's lighter 3D-printed parts for a jet engine improved fuel efficiency by 15% [24].

To support sustainability in 3D printing, policy should primarily encourage low-energy printing processes and low-impact materials with useful end-of-life characteristics. Printer design and operation can minimize energy use per printed part by using chemical processes rather than melting material; using automatic switching to low-power states when idle; and, maximizing utilization (sharing printers among users and, for some printer types, printing more parts simultaneously). Another way in which printers can minimize material impacts is by using compostable biomaterials with high print quality. Printer design and operation can also reduce waste by minimizing the use of support material (printers of all kinds often use support materials in addition to the actual modelling material to prevent part warping before they are fully formed). Policy mechanisms to achieve these priorities should include:

• Targeting financial grants or investments (either existing programs or new funds) to commercializing research in these directions.

• Removing IP barriers to enable 3D printing of repair parts for legacy products that lack existing supply chains. For example, a consumer may realize a washing machine is broken and that it only requires a small hinge to be fixed. Theoretically, a consumer with a 3D printer could go to a computer, find the appropriate CAD file and print the new part. But most CADs are proprietary. One solution would be to incentivize rights for third parties to print replacement parts for products, with royalties paid to original product manufacturers as needed. Creation of a voluntary certification system to label 3D printers with different grades of sustainability across multiple characteristics. Such a voluntary certification system could be combined with preferential purchasing programs by governments and other large institutions.

New materials and the next production revolution

Advances in scientific instrumentation, such as atomic-force microscopes and X-ray synchrotrons, have allowed scientists to study materials in more detail than ever before. Developments in computational simulation tools for materials have also been critical. Today, materials are emerging with entirely novel properties, such as solids with densities comparable to that of air. Progress in computation has allowed modelling and simulation of the structure and properties of materials to inform decisions on how the material might be used in products. Properties such as conductivity, corrosion resistance and elasticity can be intentionally built into new materials. This computation-assisted approach is leading to an increased pace of development of new and improved materials, more rapid insertion of known materials into new products, and the ability to make existing products and processes better (for instance, the possibility exists that silicon in integrated circuits could be replaced by materials with superior electrical properties). In the NPR, engineers will concurrently design the product and its constituent materials [27,28]. Among other things, the importance of new materials for manufacturing is reflected in the United States' Materials Genome Initiative (MGI). Introduced by President Obama in June 2011, the MGI aims to halve the time, and lower the cost, to discover, develop, manufacture and deploy advanced materials. A simulation-driven approach to materials development will reduce time and cost as companies perform less repetitive analysis. Simulation will also permit better products, such as stronger complex structures. Successful integration of materials modelling and data sciences into decision support for product development can also shorten the time between materials discovery and their commercial use. The Accelerated Insertion of Materials program, run by the United States' Defense Advanced Research Project's Agency (DARPA), has demonstrated such time savings. Large companies, too, will increasingly compete in the development of materials. This is because a proprietary manufacturing process applied to proprietary materials creates long term competitive differentiation [26]. Policy making at national and international levels can strongly influence the development of the materials innovation ecosystem, broaden the potential pool of collaborators, and promote adoption of more efficient investment strategies. No single company or organization will be able to own the entire array of technologies associated with an e-collaborative materials innovation ecosystem. Accordingly, a public-private investment model is warranted, particularly with regard to building cyber-physical infrastructure and developing the future workforce. For instance, new cybersecurity risks could arise because, in a medium-term future, a computationally assisted materials "pipeline" based on computer simulations could be hackable. Progress in new materials also requires effective policy in areas important for pre-existing reasons, often relating to the science-industry interface. For instance, well-designed policies are needed for open data and open science (for sharing simulations of materials structures, or for sharing experimental data in return for access to modelling tools, for example [Nature, 2013]). Advances in new materials also require close collaboration between industry, universities, research funding agencies and government laboratories. Materials research is inherently interdisciplinary. In education, students who will become experts in materials synthesis, processing, or manufacture must understand materials modelling and theory, while modelers and theorists must understand the challenges faced in industry. Major efforts are underway to develop the early materials information infrastructure and associated data standards in professional societies [29]. A need for international policy co-ordination arises from the necessity of federating elements of the cyber-physical infrastructure across a range of European, North American and Asian investments and capabilities, as it is too costly (and unnecessary) to replicate resources that can be accessed via web services with user support. Ultimately, good policies are required because of the need to change the culture of sharing data and, in particular, to facilitate a pre-competitive culture of e-collaboration. Deliberation between research bodies, firms, government research laboratories, standards organizations, and professional societies working to develop new and improved materials have predominantly been concerned with the compatibility of data formats. But this needs to evolve towards a focus on how to use these data to support decisions in materials discovery and development, along with many of the foregoing policy issues. Access to high-performance computing and cloud storage is an important element, to which pre-competitive public-private consortia and government policy can contribute. Initiatives such as the Integrated Computational Materials Engineering expert group (ICMEg) in Europe are wrestling with these issues.

The diffusion of new production technologies: What can governments do?

A critical issue is how already-developed technologies diffuse. The issue is twofold. First, it is about increasing new-firm entry and the growth of firms which are major carriers of new technology. Secondly, it is about increasing productivity in established firms which face obstacles to implementing technology [18]. The two aspects of technology diffusion-firm entry and growth, and more general absorption-involve different policy instruments. Several factors shape the diffusion process at national and international levels: (i) global connections via trade, FDI, participation in GVCs and the international mobility of skilled labour; (ii) connections and knowledge exchange within the national economy, such as the interaction between scientific and higher education institutions and businesses; (iii) the scope that exists for experimentation by firms-especially entrants-with new technologies and business models; (iv) the extent of complementary investments in R&D, skills, organizational know-how (i.e. managerial capabilities) and other forms of knowledge-based capital [30]. The causes of inefficient resource reallocation can be many, including a lack of product competition, rigid labour markets, disincentives for firm exit, barriers to growth for successful firms, and policy conditions such as restrictions on trade. For example, the sensitivity of capital investment to a change in the patent stock is almost double in countries where contract enforcement is less costly (such as Norway), relative to countries where it is more costly (such as Italy) [31,32]. examined how long it takes technologies to be adopted in developed and developing economies, and how intensely those technologies are used. For 25 technologies, the authors find a convergence in adoption rates across countries, but divergence in the intensity of use. Learning how to use new technologies is still a challenge for companies in many developing economies. Conditions which facilitate such learning include open trade, efficient skills allocation, managerial quality, the volume of business R&D, and the capacity of governments to develop and implement e-government services [30]. Institutions for technology diffusion are intermediaries, structures and routines that facilitate the adoption and use of knowledge, methods and technical means. Some of the institutions involved, such as technical extension services, tend to receive low priority in the standard set of innovation support measures. But there is evidence that they can be effective, if well designed. The conventional rationale for supporting institutions and mechanisms for technology diffusion builds on information deficiency and asymmetry and other market failures. Enterprises (especially SMEs) frequently lack information, expertise and skills, training, resources, strategy, and confidence to adopt new technologies; suppliers and private consultants can experience high transaction costs in trying to diffuse technologies; and finance for scale-up and implementation is not always forthcoming. Support from technology diffusion institutions seeks to guide and support enterprise capabilities, adoption, and justify investment choices in new technology. In the fast-moving environment of next generation production technologies, the conventional market failure rationales for institutional intervention are likely to become even more important, to aid potential users to sift through burgeoning amounts of information and to support decision making in the context of rapidly changing technologies and expertise requirements. Innovation systems invariably contain multiple sources of technology diffusion, such as universities and professional societies. Table 1 offers an initial typology. The need for new strategies to promote institutional change, knowledge exchange, capacity development, and demand-led initiatives for technology diffusion has given rise to new initiatives, some of which are experimental. New production technologies have stimulated partnerships that cross-sectoral boundaries and address problems of scaling up from research to production. Alongside established applied technology centers, such as the Fraunhofer Institutes in Germany, there is an increase in partnership-based approaches. An example is the US National Network for Manufacturing Innovation (NNMI). The NNMI uses private non-profit organizations as the hub of a network of company and university organizations to develop standards and prototypes in areas such as 3D printing and digital manufacturing and design. Analogous to the rise of open sharing of research articles and data is the emergence of libraries promoting sharing of technological building blocks. For example, Bio Bricks is an open-source standard developed at MIT to enable shared use of synthetic biology parts through the Registry of Standard Biological Parts. Such open-source mechanisms in biotechnology exist against a backdrop of traditional proprietary biotechnology approaches. For example, the Innovation Corps (I-Corps) programmer was established by the US National Science Foundation (NSF) in 2011 to accelerate commercialization of science-intensive research. Teams of researchers and budding entrepreneurs receive grants to attend training, which encourages ongoing interaction with customers and partners. The program enhances the knowledge of participants and their capacity to start companies around NSF-funded research [33]. Attention to the procurement of innovation by government agencies has grown across many countries, often targeted to SMEs. Incentives such as R&D tax credits, regulations and standards are also being used to encourage pre-commercial R&D activities, such as feasibility studies and prototyping. The effectiveness of technology diffusion institutions depends in part on firms' absorptive capabilities. This suggests the importance of efforts to foster demand through such mechanisms as innovation vouchers, which encourage users to engage with knowledge or technology suppliers. Several countries (including the United Kingdom, Ireland, and the Netherlands) have promoted innovation vouchers

Table 1: Initial typology of institutions for technology diffusion.

Type	Operational mode (primary)	Example
Dedicated field services	Diagnostics, guidance and mentoring	Manufacturing Extension Partnerships (US); German Industrial Collective Research for SMEs
Technology-oriented business services	Advice linked with finance Capacity development	Industrial Research Assistance Program (Canada); I-Corps (US)
Technology transfer offices	IP licensing	University technology transfer organisations (multiple countries)
Applied technology centres	Contract research	Fraunhofer Institutes (Germany), TNO (Netherlands)
Technology information exchange	Technology community networking	Knowledge Transfer Networks (UK)
Demand-based behavioural change	Knowledge transfer incentives	Innovation vouchers (multiple countries)
Technology partnerships	Collaborative applied research Prototyping and standards	NNMI (US)
Open-source sharing	Open source sharing Virtual networks	Registry of Standard Biological Parts (US)

The next production revolution and developing countries

Over recent decades, the world has witnessed a growing international integration of markets for capital, intermediate inputs, final goods, services and people. The increased partitioning of production in GVCs has drawn attention to the economic consequences of operating in different parts of a GVC [35]. GVCs are constantly evolving [34]. Recent OECD work finds little evidence at this time of the reshoring of activities from emerging to advanced economies as the result of automation, cost-saving technological change and other conditions [36]. However, evidence suggests that European companies which intensively use robots are less likely to locate production abroad. And features of some technologies, such as 3D printing-through which bespoke products or components can be made on the basis of specifications prepared on a computer anywhere in the world - could lead to some production being brought closer to developed-country markets. Developments in China are also likely to play a role. Aside from the fact that China accounted for 20.8% of global manufacturing output in 2013, China's goal of increasing the knowledge content of domestic production will expand the range of markets in which China competes and will also contribute to the development of production technologies in those markets Labour-intensive industries which predominate in many developing countries, such as garments, shoes and leather, furniture, textiles and food, could be less susceptible to NPR's impact, since many processes in these industries are yet to be fully (or economically) automated. Other developing-country industries such as the electrical and electronics and machinery sectors, particularly those facing growing wages, are likely to be significantly affected by the NPR, given their high potential for automation. In other industries, such as automotive manufacture, adopting NPR technologies is expected to be determined not so much by wages or the potential for automation, but by domestic demand and consumers' growing desire for quality and customization. However, technological change could quickly alter the validity of the above observations and threaten capacity in developing countries. For instance, because of dexterity requirements, footwear manufacture has to date been labor-intensive. But a global apparel company recently built a shoe manufacturing facility in Germany which is fully automated and permits significant customization. The facility consists of machines set in two production lines and anticipated to take up to five hours for a full production cycle (which currently otherwise requires several weeks) [37]. Sewbo, a new start-up, is developing automation for garment fabrics where fabrics are woven by machines and cut by computer-controlled cutting machines. And intelligent robots could soon replace service functions, like call centres or accounting operations, which have become growth pillars in many developing countries. A challenge for firms in developing countries will be their ability to upgrade machines, factories and business ICT systems, which are required for interconnected production. While 'islands of modernity' exist among firms in many developing countries, the capital stock is often based on older machines and out-of-date or obsolete ICT systems, which are difficult to retrofit with new technologies. NPR technologies operate with tolerances, and with technical standards and protocols, that developing-country firms are often unfamiliar with. And NPR technologies often require a continuous uninterrupted source of power, which is not available in some developing countries. While incremental approaches to adoption will help, the greatest benefits of the NPR accrue when production processes operate as systems Many emerging production technologies require large financial outlays, which are generally recoverable over periods above five years. Investments in new technologies are often not limited to specific technologies but require a range of complementary expenditures. Investments in robots, for example, usually entail investments of similar size in peripherals (such as safety barriers and sensors) and system implementation (such as project management, programming, installation and software). Financing NPR investments can thus necessitate: a range of financing institutions, such as venture capital firms and development banks; machinery-related term lending; and specialized SME and start-up lending. Such a breadth and depth of financial services is only available in a few developing countries The range of policy issues relevant to an NPR is extremely broad. Evidently, production is affected by many types of policy, from those on skills and training, to policies affecting domestic and international competition, to tax codes that affect investments in machinery and software, to policies which influence the efficiency of judicial systems and the effectiveness of bankruptcy laws, to policies on infrastructure and financial services. In addition, this paper has pointed to the roles of a "meso" level of policy, such as the design of particular institutions and programmers. The breadth of relevant policy issues underscores that some forms of policy co-ordination may be needed. The technologies covered in this report result from science. Policymakers need to be attentive to such matters as: the procedures for allocating funds for public research; the balance between support for applied and basic research; a variety of institutional features and incentives which shape open science; the frameworks that provide incentives for firms, public researchers and public research institutes to commercialize research, while protecting the public interest; the development of well-designed public-private partnerships; the implementation of efficient, transparent and simple migration regimes for the highly skilled; the facilitation of linkages and networks among researchers across countries; and, the creation of a judicious evidenced-based mix of support using both supply- and demand-side instruments. Identifying priorities for government-funded manufacturing research programmers and initiatives is increasingly challenging due to the convergence of technologies and the growing complexity of modern manufacturing. To assess the impact of R&D investments-and decide where policy efforts should focus-policy makers need to take account of the increasingly blurred boundaries among manufacturing research domains. Technology R&D programmers can be too "siloed" if mechanisms are not put in place to support multidisciplinary and challenge led endeavors. Policy makers should avoid cookie-cutter KPIs that do not account for the systemic nature of the NPR. OECD research over recent years has highlighted the role of new and young firms in net job creation and in nurturing radical innovation. New firms will introduce many of the new production technologies. But Criscuolo, Gal and Menon. (2014) find declining start-up rates across a wide range of countries since the early 2000s. Governments must attend to a number of conditions which affect this dynamism. These conditions have been treated in detail in other analyses [38,39]. One major challenge to the IP system comes from the emerging ability of machines to "create", an ability which until now was restricted to humans. For example, KnIT, a machine learning tool developed by IBM, was successfully run to identify kinases with specific properties among a set of known kinases. Those properties were then tested experimentally. In other words, the specific properties of those molecules were discovered by software, and patents were filed for the inventions. A second challenge stems from the ability to digitalize physical objects. 3D printing, for instance, might create complications in connection with patent eligibility. For example, if 3D-printed human tissue improves upon natural human tissue, it may be eligible for patenting, even though naturally occurring human tissue is not. The future of these technologies could be affected by how IP and patent systems adapt. The distributional effects of new production technologies require policies beyond the domains of science and innovation. The possible measures are many, from earned income tax credits to the provision of resources for lifetime learning and job retraining. Tackling an uneven distribution of skills is a key to lowering wage inequality. Among other reasons, this is because work requiring lower educational attainment is more susceptible to automation [40]. Rapid technological change could challenge the adequacy of skills and training systems to match demand and supply for new skills. For some production technologies, current skills supply is insufficient. Improving the efficiency of skills matching in labour markets supports productivity [13]. It is as yet unknown whether new generations of production technology will significantly alter past norms as regards skills supply and demand balances (although digital technology could of course play a role in augmenting skills supply, for instance through massive open online courses). Many of the technologies examined in this report require more interdisciplinary education and research. The increasing complexity of some scientific equipment also demands the use of multiple skill types. But some education systems and individual institutions may not be responding as well as is needed. Achieving interdisciplinarity is not a new challenge. But more needs to be known about the practices adopted across research institutions, teams and departments-private and public-which enable interdisciplinary education and research. Policymakers could seek to replicate, where appropriate, the approaches of institutions successful in fostering interdisciplinary research, such as Stanford's Bio-X. Generic skills such as literacy, numeracy and problem solving provide a foundation for the acquisition of technology-specific skills (whatever those technology-specific skills turn out to be in future). Good generic skills help to "future proof" human capital. Many other policy issues that affect skills systems today will continue to be important, but it is not evident that a next production revolution would raise their importance. Such issues include: (i) establishing incentives for institutions to provide high-quality teaching; (ii) supporting firm-level training and life-long learning; and (iii) ensuring that any barriers to women's participation in STEM are removed.

Conclusion

The manufacturing industry is one of the sectors that are influenced by the fourth industrial revolution. Similarly, manufacturing is moved from Industry 3.0 phase into the industry 4.0 phase. In industry 4.0 the manufacturing machines are connected to a virtual environment for each physical machine that presents the manufacturing process in real-time. Therefore, factories are one of the entities that are encouraged to retrain and develop their operators to be able to gain all benefits of industry 4.0. The technologies covered in this report result from science. Policymakers need to be attentive to such matters as: the procedures for allocating funds for public research; the balance between support for applied and basic research; a variety of institutional features and incentives which shape open science; the frameworks that provide incentives for firms, public researchers and public research institutes to commercialize research, while protecting the public interest; the development of well-designed public-private partnerships; the implementation of efficient, transparent and simple migration regimes for the highly skilled; the facilitation of linkages and networks among researchers across countries; and, the creation of a judicious evidenced-based mix of support using both supply- and demand-side instruments. The nanotechnology is a major breakthrough and is revolutionary as it will create extraordinary Nano world in the present century. This research paper aims to clarify the required knowledge and learning for a worker to operate the manufacturing processes associated with some of the capabilities of Industry 4.0 and Nano technology. This study provides several results, the most important of which is the focus on the rehabilitation of operators using modern technologies in alignment with the Fourth Industrial Revolution.

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